APPENDIX.

*Report on the Experience of the Coast Survey in regard to Telegraph Operations, for determination of Longitude, &c.**

[Extracted from the Proceedings of the Am. Association for the Advancement of Science, 1849, p. 182.]

Mr. SEARS C. WALKER, Assistant in the United States Coast Survey, by instructions from the Superintendent, communicated the substance of his recent Report on the Experience of the Coast Survey, in regard to telegraph operations, as follows:—

The duty of communicating to the Association the experience of the United States Coast Survey, in regard to telegraph operations, has been assigned me by the Superintendent.

The first mention of the electro-magnetic telegraph, in connection with longitude operations, as far as I know, was made, in 1837, by M. Arago to Dr. Morse.

The first practical application of the method was by Captain Wilkes, in 1844, between Washington and Baltimore. Two chronometers, previously rated by astronomical observations in the vicinity, were brought to the two telegraph offices, and were compared together through the medium of the ear, without coincidence of beats. This process is accurate enough for geographical or nautical purposes; but its precision stops short of the mark where the requirements of geodesy begin. In fact, two clocks beating the same kind of time, when placed side by side, cannot be compared together, by the human ear, with sufficient precision for geodetical purposes. The subsequent experience of the

* This article should have appeared in this Journal, at an earlier day; but the very tardy issuing of the volume of 'Proceedings,' &c., in which it is printed, prevented our publishing it at the same time with the article on the 'Electro-chronograph' by John Locke, which appeared in September last year, (vol. viii, p. 231.)

It is well known that a personal controversy exists among claimants in this interesting research. It is not our purpose to discuss its merits, did we understand them. The responsibility of published statements must rest with those who make them, and we wish it distinctly understood (as we suppose indeed it now is), that the Editors of this Journal hold themselves responsible for no facts or opinions published in these pages, unless uttered in their own individual or collective names. No articles find admission to our pages without the name of a responsible author, and beyond the strict limits of improper personality, the authors alone are to be held responsible for the ground assumed in their several communications.

A long experience has convinced us that there is no ground, except that announced above, on which we can safely stand, in cases where controversy exists in matters of science.—*Editors Am. Jour. Sci.*

Coast Survey has shown, that where several astronomers make independent comparisons of clocks, in this manner, two seconds of arc, or twelve-hundredths of a second of time, is an average discrepancy between their results.

The subject of telegraph operations for longitude had engaged the attention of the Superintendent of the Coast Survey, previous to the experiment of Captain Wilkes; but the orders received by me for this purpose, bear date of November 24, 1845. In 1846, the very first season in which two astronomical stations of the Survey were brought in connection by the Morse telegraph lines, the work of connecting them together, in longitude, was commenced in earnest by the Superintendent of the Coast Survey. The coöperation of the National Observatory, as one of the stations, was freely tendered by its Superintendent, Lieut. Matthew F. Maury, U. S. N., and accepted by Prof. Bache. The detail of the operations was left to me. The Comptrollers of the Public Schools of Philadelphia had tendered the free use of their High School Observatory, under the direction of Prof. E. Otis Kendall. An additional station, at Jersey City, was fitted up by the Coast Survey, with astronomical instruments, under the direction of Prof. E. Loomis. The three stations were connected by special junction lines, (built at the expense of the Survey,) with the main Morse line, from Washington to Jersey City, under the Presidency of the Hon. Amos Kendall. Three full sets of telegraph keys and receiving magnets were made for the purpose, at the machine shop of the Coast Survey Office, under Mr. Saxton's directions, and three Morse registers were purchased for the occasion, from Mr. Clark, an instrument-maker in Philadelphia.

Owing to the imperfect insulation of the lines, the connection of Jersey City with Washington failed that year; but the Washington and Philadelphia stations were connected together astronomically on the 10th and 22d of October.

The method of comparison, by coincidence of beats of solar and sidereal timekeepers, was not introduced this year; but the equivalent one was employed, namely, the exchange of star signals. These are the dates of instants of the passage of a star over the wires of the eye-piece of the transit instrument, signalized by tapping on the telegraph key at one station, and recording it on the Morse register at both.

Since this operation of making the time of a star's transit legible on any number of registers at any number of stations is likely to come into general use, in geodesy, geography, and hydrography, so long as there remains on the earth's surface any two important points whose relative longitude is unknown, the origin of the method must be a subject of historical interest.

The idea of substituting for clock signals, which have no immediate relation to longitudes, those of the times of a star's tran-

sits, which have such a relation, occurred in the winter of 1845 and 1846, in a consultation between the Superintendent and myself. Which made the first suggestion, I cannot now say, nor is it a matter of much importance to either of us personally. As respects the service in which we are engaged, the origin is a matter of importance. It is a subject of just pride to those engaged in it, that the first conception of the method, and the first practical operation with it, are peculiarly its own. The blank form, No. 2, of telegraph operations, drawn up by me in the spring of 1846, and lithographed for use at the three stations, is headed "Coast Survey," and is described in my lithographed "Circular to the Telegraph Operators." It is dated "Coast Survey Office, September 25th, 1846." In pursuance of this programme, on the 10th of October, the transit of the star 2838 Bailey, over the seven wires of the west transit instrument of the Washington Observatory, was signalized by Lieut. Almy, U. S. N., the officer having charge of that instrument. This transit was noted on the Washington clock, by Lieut. Almy, and also by myself, comparing together, by the ear, the seven key beats, with the clock beats. The same key beats were also noted by Prof. Kendall, at Philadelphia. This was the first practical application of the method of star signals, which is sooner or later to perfect the geography of the globe. The signals were made visible on the running fillet of paper. The fillet was not then furnished with a visible graduation.

The *personal graduated clock register*, and the *personal register of the star signal*, were both made in an evanescent form on the *auditory nerve* of the ear. Two years later, (1848,) the *visible* was substituted for the *auditory* register, in the month of July. In the month of November, the *automatic visible register* took the place of the *personal visible register*, and constituted the last step in the improvement of the art of telegraph operations for longitude.

Whether we use the *personal auditory*, *personal visible*, or the *automatic visible* register, the theory of the resulting longitudes is the same. They differ only in the superior facility, precision, and permanency of the latter.

This analytical theory, from beginning to end, belongs to the Coast Survey Service. My letter to the Superintendent, on file in the Coast Survey Office, dated October 3d, 1846, contains the *analytical theory* of longitudes by star signals, whether recorded on a *personal auditory register*, as in 1846, a *personal visible register*, as in 1848, or an *automatic visible register*, as in 1849.

I deem it, therefore, but a duty to the service in which I am engaged, to declare, in the presence of the members of the Association, that, with the single exception of the experiment between Baltimore and Washington, by Captain Wilkes, in 1844, I

know of no telegraph operations for longitude, and of no step in the improvement, or perfectionment of the art in Europe or America, which have not been the work of the officers proper of the Coast Survey, or of commissioned officers and civilians acting temporarily as assistants.

After this digression, I resume the recital of our experience in the Coast Survey.

In 1846, we connected together, in longitude, the Washington and Philadelphia stations. In 1847, the programme left unfinished in 1846, by the imperfection of the lines, was resumed and completed, and Washington, Philadelphia, and Jersey City, were connected together. On the 27th of July, 1847, the method of coincidence of beats, used so successfully by R. T. Paine, Esq., in the chronometric operations for longitude, in Massachusetts, and by Struve and Airy in their chronometric enterprises, was applied to the telegraphic comparisons of the Philadelphia and Jersey City Clocks. This method of coincidences was used in combination with exchanges of star signals in the telegraphic operations of the Coast Survey, in 1848, when the Cambridge Observatory, under Prof. Bond, and the Stuyvesant station in the garden of Dr. Rutherford, New York, under the direction of Prof. Loomis, were connected together by the Coast Survey. The lines of junction with the main line, under the presidency of the Hon. Francis O. J. Smith, the telegraph apparatus, and the astronomical instruments of the Stuyvesant station, were furnished at the expense of the Survey. During these operations, in July and August, Prof. Bond proposed to substitute the *automatic* instead of the *personal seconds circuit breaker*, and submitted to me a sketch of his plan for effecting the *make* and *break* circuit by the escapement beat. On my special recommendation, by report to the Superintendent, dated August 11th, 1848, an order was given to Mr. Bond for the completion of a *circuit breaker clock* on his plan.

The *automatic clock circuit breaker*, named by Dr. Page, of Washington city, an *electrotome clock*, is not an American invention. It was used more than ten years ago, by Messrs. Wheatstone, Bain, and Steinheil, in Europe. It is due also to Prof. Bache, Mr. Saxton, and Dr. Morse, to say that each of them suggested the use of *clock electrotomes*, in 1846, with particular descriptions of the methods. I was deterred from using them in connection with the observing astronomical clocks at the time, from apprehension of disturbance of their rates.

This apprehension was in reality groundless, and I would here make the remark that all the methods then and since proposed or tried, for *clock electrotomes*, and all the various methods of registering, are precise enough for the purposes of geodesy. Hence, in giving preference to one over another, we should only be guided by considerations of facility and economy of outfit, and of facility of making, reading, and preserving the printed registers.

After concluding the work between Cambridge and New York, in 1848, the month of October was employed by the Coast Survey in connecting Philadelphia and Cincinnati, by means of the O'Reilly Morse lines. The Philadelphia junction line was made by the Coast Survey. The Cincinnati junction line of half a mile in length was erected by Henry O'Reilly, Esq., and presented to the Cincinnati Observatory, as his subscription towards that establishment. The transit and telegraph instruments for Cincinnati, were supplied by the Coast Survey for Prof. Mitchel.

The labors of the year 1848 comprise some 1800 observed transits of stars, 800 comparisons of chronometers, by coincidences of beats taken at the stations, 5,000 transits over wires, for determining the personal equations of the officers of the Survey, many thousand exchanges of personal clock signals, and 600 of star transit signals.

If even this prodigious accumulation of statistics was considered a gain of many fold over the old method of obtaining astronomical longitudes, what shall we say of the automatic process employed in 1849, where one night's exchange of star-signals between Philadelphia and the Seaton station, printed automatically on the single sheet of paper now before you, is worth the whole list of statistics collected by the Coast Survey between Philadelphia and Washington, in 1847.

The subject of the invention of the automatic clock register is explained in full in my Report to the Superintendent of the Coast Survey, of December 15th, 1848, which, with his letter communicating it to the Treasury Department, and that of the Hon. Robert J. Walker, communicating both to Congress, have since been extensively circulated by the press.

I will not here allude to the respective claims of Americans for priority or superior excellence of inventions and suggestions, believing that it will be becoming for all of us, to look to the great work that has been accomplished, by our united efforts, rather than to the single share of each.

Feeling the responsibility under which I was acting, I spoke with caution on the subject of the comparative excellence of the automatic printing method; though some of my friends thought that its merits were overrated. I appealed to the experiments that were to be made in the campaigns of 1849 for a test of the new method. That which was then anticipation only, is now reality; and I am able to say, from recent trials, between Cambridge and Washington in January last, and between the Seaton station under my care at Washington, and the stations at Philadelphia under Prof. Kendall, and Hudson, Ohio, under Professor Loomis, in July and the current month, that the excellence of the new method surpasses all that I ventured to hope for in December last. I then ventured to claim for the automatic printing

method a ten-fold gain over the old one. I now find that one transit over one wire is worth four wires by the old method, and that ten transits over wires may now be printed, where one was done before; making a gain by the new or automatic method of some forty-fold. I mean by this the gain from multiplication of transits over wires, and superior precision of each. We cannot in one night obtain the advantage of the average of the meteorological peculiarities of forty.

The various clock *electrotomes* may be thus classified:

Author.	Date of invention or suggestion.	Description of method.
Wheatstone . . .	1840.	Circular disc on arbor of second's wheel.
Bain	"	Sliding rod moved by pendulum.
Steinheil	Not known.	
Saxton	At launch of Frigate Raritan.	Platinum tilt hammer moved by pendulum.
Saxton	In 1846.	Globule of quicksilver struck by pendulum.
Johnson & Speed .	In 1847.	Platinum tilt hammer struck by teeth of the minute wheel.
Bond	In 1848.	Escapement electrotome.
Mitchel	"	Quicksilver struck by pendulum.
Locke	"	Platinum tilt hammer struck by teeth of seconds-wheel.

I have already remarked that I believe that all these electrotomes will succeed in practice, without injury to the rate of the clock. In making our selection we must look to facility and cheapness of construction, and to uniformity of graduation of the time scale. In the present state of my experience on this subject, I prefer the form now in use at the Seaton station, recently applied by Mr. Saxton to the Hardy dead-beat clock of the United States Coast Survey, imported by its late Superintendent, Mr. Hassler, and by him described in the Transactions of the American Philosophical Society. The electrotome is on the model used by Mr. Saxton several years ago, at the time of the launch of the frigate Raritan, at Philadelphia. The perfect gravity escapement, (resembling, I believe, that which was recently invented by Dr. Locke,) has been substituted by Mr. Saxton for Hardy's springs. Two pounds have been added to the weight of the clock to prevent danger of stopping by increased friction. In this condition Mr. Saxton expresses the opinion that the clock of the Seaton station is the best clock extant. It has broken the circuit for forty days without interruption, and has in no instance deviated in an appreciable amount from its losing rate of one-tenth of a second per day. For a more full understanding of it, I refer you to the accompanying description and drawings by Mr. Saxton.

I have spoken of the *automatic circuit breaking clocks;* it remains to notice the *automatic registers.* The first in order is the registering fillet of Dr. Morse, described in my report of Decem-

ber last. This has no maintaining power. It may be made to run with one winding for fifteen minutes; but gives uncertain records during the time of winding.

In reading off the dates of the signal electrotomes on the clock electrotome scale, a small strip of paper or of horn, is used, which in ten inches diverges from a point to the extent of a second on the register. This is placed on the fillet of paper, so that its width equals the distance of the clock and signal electrotomes. The tenths of seconds are read off at sight, and hundredths are set down by estimation. A correction for rate of the actual time scale on that of the normal or measuring scale might be applied if we wished; but on experience of a month at the station, we find that the neglect of it brings an error not greater than that of the conjecture, relative to the hundredth of the second, so that in practice we may dispense with the correction altogether.

The next method is the *chemical* method of registering with the main circuit. I have made full experiments with it, and think that the advantage of avoiding the errors of the relay and primary armature time, are more than counterbalanced by the difficulty and irregularity of the action of the current, the indistinctness of the edges of the scale pauses after the paper is dry, and the irregularity of hygrometric expansion of the paper.

In the experiment of measuring the velocity of the hydro-galvanic current, the method will be useful, as it removes all questions relative to *armature* time, though perhaps it substitutes a longer delay, which I may call *chemical action* time.

On the subject of the velocity of the hydro-galvanic current, I would remark that the experiment of January 23d, between Cambridge, Philadelphia, and Washington, indicates a velocity about one-tenth of that of light. This value, though probable, is by no means certain, and I would wish to speak with caution till more experiments are made.

The third form is the register on a disc with concentric circles, as described by Prof. O. M. Mitchel, in his letters to the Superintendent.

Prof. Mitchel's experience of the despatch and precision of the work, confirms my own. I have no doubt that his method of registration is excellent; perhaps not inferior in compactness, precision, and facility of reading off, to the Saxton sheets. I should wish for the opportunity of personal inspection before giving an opinion conclusively on the subject.

The fourth form of the register is Mr. Saxton's invention of this year. I submit his drawings of the machine. It is somewhat on the plan of his celebrated ruling machine. The cylinder now before the Association contains the culmination of the planet Neptune and the stars near his parallel, printed by me at the Seaton station, Aug. 11, 1849. It might seem that the sub-

ject of the place of the planet Neptune is foreign to the purpose of telegraph operations. Such is not the case; for we have used this planet as a fundamental star. I take occasion, therefore, to remark that the observations of the culmination of Neptune on four nights in the month of August at the Seaton station, by Pourtalès and myself, show that my Ephemeris, published by Prof. Henry in the Smithsonian Contributions to Science, agrees with the heavens within half a second of arc. From this close agreement it may be inferred that if the Neptune of Prof. Peirce's theory and my elements were conceived to be a planet, placed side by side in the heavens with the true one ever since its discovery, the two would form a double star of an order so close that not even the great Cambridge refractor could detect their duplicity.

An objection has been urged to the Morse registering fillet, that it is too voluminous for the quantity of matter recorded. This objection and that of expensiveness, occur with more force to the metallic cylinder, however accurate be its indications. To remedy this evil, Mr. Saxton has contrived a sheet of paper which encloses the cylinder and lasts for about two hours of constant work. The sheets and registering fillets now submitted for the inspection of the Association, contain the comparison of the printed record of the culmination of the stars in the Dolphin. The Saxton sheet, the chemical fillet, and the Morse fillet, are triplicate records of the same identical star signals. The result of the reading, as far as experiments have been made, is, that all kinds of registers at the same place read alike. It is worthy of remark that these registers contain the printed record of the transits of both components of the double star Gamma Delphini, printed with ease on each of the forty-five wires of the Wurdeman's diaphragm, making ninety imprints in a culmination.

From my experience in printing the transit of this pair of double stars, I am led to the conclusion, that four stars forming a quadruple star, when at proper distance, may all be printed at the time of their transit over a diaphragm of fifty wires, making two hundred imprints for one transit, a rapidity of playing on the key far below that of good execution on the piano.

The other sheet before you contains the longitude between the Seaton station and Philadelphia. It was registered at Washington. The Morse fillet on the reel now before you is the duplicate Philadelphia register.

This work was performed last Monday night. You will notice a curious occurrence on several occasions that night. Three distinct telegraph operations were going on at once. The Seaton station clock was graduating the time scale for both stations. Two stars differing in right ascension by about the longitude of the places, were in the two telescopes at the same time, and the

imprints of the transits are interspered, without confusion on the register. Since one wire at each station gives the longitude of the places, we can find cases where the work of a single second has effected this purpose better than a year's work could do without the telegraph.

The diaphragms of nine and eleven tallies (45 and 55 wires,) made by Mr. Wurdeman, formerly the Mechanician of the Coast Survey, are so nearly perfect in their structure that the probable error of his locating of any single wire, in reference to a normal location with equal intervals, is only four hundredths of a second of time. This precision is a matter of great importance in the use of a diaphragm of so many lines, whose equatorial interval, unless in the case of known symmetry, would need a special determination.

Of all the different kinds of registers here alluded to, I prefer the sheet of Mr. Saxton. One sheet filled on both sides, or two pages, will contain an ordinary night's work. A year's work will make a book of some three hundred pages, on the margin of which may be entered the ordinary remarks for an observing book, relative to the state of the level and meteorological instruments, name of stars observed, and instrumental deviations.

If folded up, or bound and put away for a century, the reduction of the work will then be as easy as at first.

In fact, we may, with the metallic cylinder, electrotype the plate; or, using copper, we may print from it without. And, in the case of the paper sheet, instead of Saxton's graver, with Indian ink, we may employ a pen, with lithographic ink, and multiply copies at pleasure, whenever we choose. When we consider the compactness of the register on Saxton's sheet, we may perhaps find that the publication of transit observations will best be made by the lithographic process, applied to the printed telegraph sheets; thus giving to the world the printed record with all the accuracy of a daguerreotype. The registering fillet now exhibited to the Association, contains the culmination of both limbs of the moon, printed by myself, on the 3d of August last, on 35 wires of the diaphragm. By mean of the results, the probable error of the imprint of a transit of single limb, over a single wire, is the sixteenth of a second; whereas, in 1846, with the great Washington Equatorial, and a power of 300, I found that, with the old method, my probable error, by 66 trials, was twice as great, namely, the eighth of a second. Thus it appears that the measure of precision is twice, and the weight four times, as great, in the new method, as in the old.

No labor of training for the work is needed. Master Langton, the youngest Assistant at the Seaton station, printed the transits of four stars, on the 18th July, for his first trial. The fourth transit is on the register now before you. On reading off Master

Langton's imprints, we find them as accurate as any of our work, and far more so than that of the most experienced observer by the old method.

A hundred wires is a high estimate for a night's work of an observatory, by the old method. I have printed fifteen hundred wires, without fatigue, in one night, by the new. Since each wire is worth four of those of the old method, we have six thousand to one hundred, or sixty to one, as the relative efficiences of the night's observations.

When we reflect, that the probable error of one transit, over one wire, is only the sixteenth of a second, and that with five wires it is only a thirty-sixth part, or three hundredths of a second, it is manifest that one tally, or five wires, is ample for all ordinary work. In fact, one wire is sufficient for most of the purposes of astronomy. I have been led, on consideration of all the facts known from the experience of the Coast Survey, at the Seaton station, to make the following remark relative to the precision of our work, after proper adjustment of the transit instrument, or measurement of its deviations from a normal state: *The printed transit of a fundamental star over any wire of Wurdeman's diaphragm, and that of a star, planet, or comet, whose place is sought, over another wire—both reduced to the centre, on the supposition of uniformity of interval—give the place of the object sought, with a precision not much below that on which rest the present elements of all the bodies in the solar system.*